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Liquid superheat in heterogeneous nucleation on a rough copper surface

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In many engineering applications liquid superheating is a nuisance and the designer's concern is to keep the system free from this unwanted phenomenon. In the present paper we have presented the results of an experimental investigation which will help the designer to predict the degree of superheat once he knows the specific heat of the liquid and the roughness of the surface used. A relation of the form

$$\Delta T_{su} = [K_1 + K_2 C_p]\,[10]^{3.0/R}$$

has been suggested, which gives fairly good agreement with the experimental value for methanol, *n*-pentane and Freon 11 on a copper surface.

1. Introduction

Size distribution of the active cavities on the boiling surface is the most important parameter affecting the limit of superheat in heterogeneous nucleation from a metal surface (Aladyev 1973, Afgan 1975, Blander 1975, Cole 1974, Skripov 1974). For most of the engineering work it is not economically feasible to know the exact size distribution of the active cavities, but a more general and accepted way is to specify the condition of the surface by measuring the roughness with the help of a profilometer and to express the r.m.s. roughness in microinches or micrometers.

In the present note I have presented the results of an experimental study in which the maximum superheat temperature in heterogeneous nucleation has been determined.

2. Experimental

The experiments (figure 1) were performed at atmospheric pressure by boiling methanol, *n*-pentane and Freon 11 on cylindrical copper surface (of appreciable thermal capacity $\approx$ 40 Joules/°C) placed vertically (for the ease of fabrication and manipulation) in the liquid. Heating was done by an electrical cartridge heater fitted inside the inner slot of the cylinder (figure 2). The liquids (L.R. Variety) were kept at their saturation temperatures (zero subcooling). Five

different surface roughnesses (R) were tried. Of the five surfaces I (~41 μ in), II (~18 μ in) and III (~10 μ in) were prepared by rubbing with different grades of emery cloth. Surface IV (~164 μ in) was threaded and V (~400 μ in) was

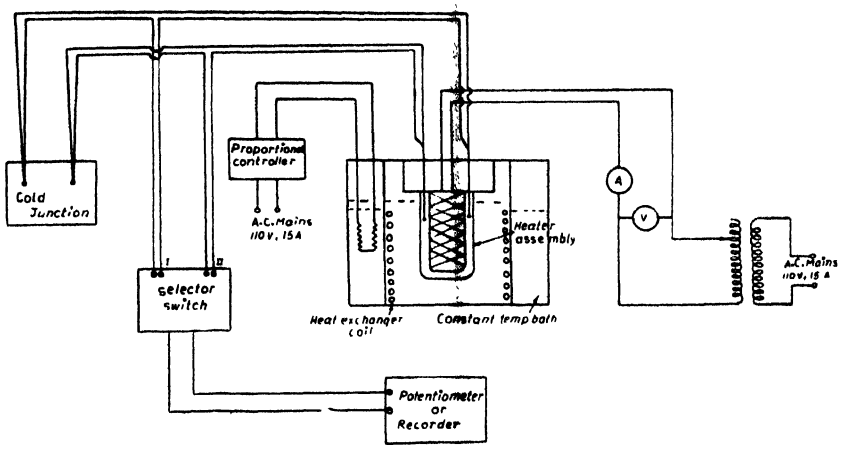

Fig. 1.

Knurled on the outer surface. The roughnesses were measured with a "Surf-indicator" profilometer. The experiments were carried out in both the steady state and the transient loading conditions (exponential period ~40 sec). Higher

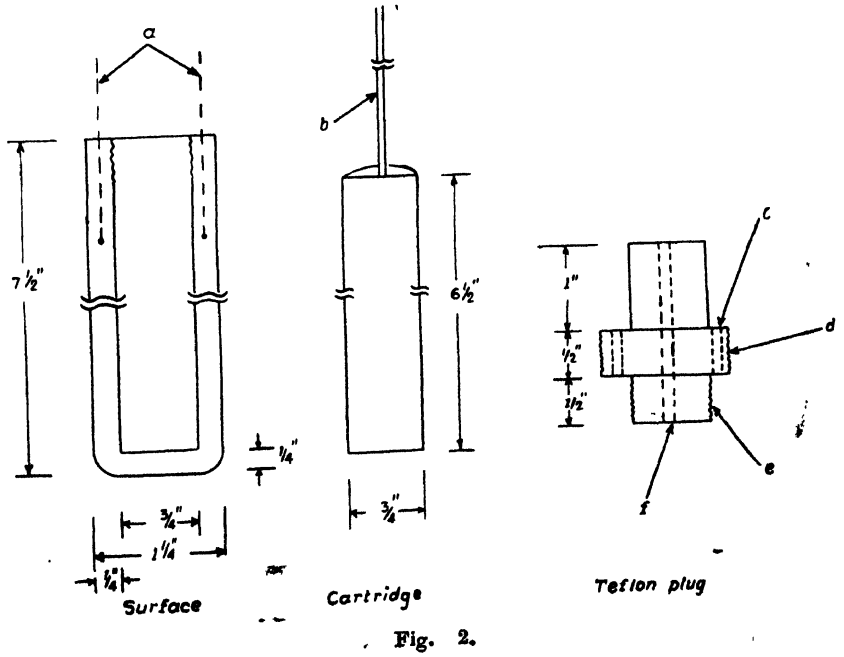

Fig. 2.

superheats were obtained under transient loading conditions (Basu 1976, Sakurai 1971). Each liquid surface combination was repeated several times to ensure the reproducibility of the results within 15%. The experimental surface was allowed to cool to 10°C and left at that condition for about half an hour, after each experimental run, and thus the active cavities were deactivated and the surface became ready for the next heat run. The transient superheat temperature was taken as the maximum attainable superheat in this experiment.

Table 1

Liquid	b	K	C_p Cal/gm
Methanol	3·0	20	0·715
n-Pentane	3·0	16	0·557
Freon 11	3·0	10	0·208

3. Discussion

Maximum superheat temperature (ΔT_{su}) is ploted against $1/R$ on a semilog graph and is shown, in figure 3, as straight lines.

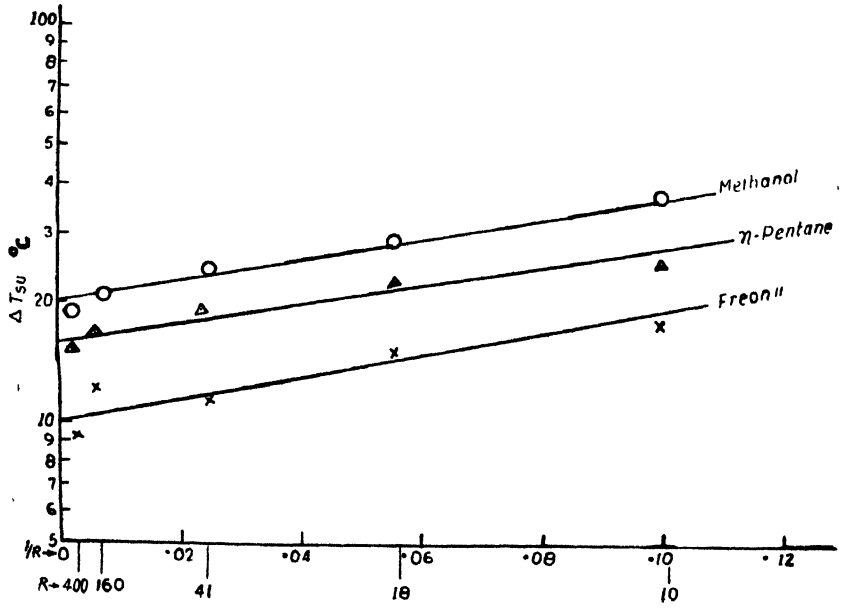

Fig. 3.

Therefore,

$$\log_{10}(\Delta T_{su}) = b \times \frac{1}{R} + \log_{10} K$$

$$\Delta T_{su} = K[10]^{b/R}. \qquad \ldots (1)$$

Again from figure 3 we see that the slope b of all the three lines are practically the same but the intercepts K are different. Table 1 gives the values of b and K for the three liquids.

We are actually concerned here with the premuclation stage of the boiling heat transfer. At this stage the heat is transferred from the hot solid surface to the adjacent liquid boundary layer and hence liquid specific heat is one of the most prominent physical parameters need to be considered.

Figure 4 shows a plot of the values of K and the corresponding values of specific heat C_p, from which we can develop a correlation

$$K = [6{\cdot}0 + 19{\cdot}6 C_p] \qquad \ldots (2)$$

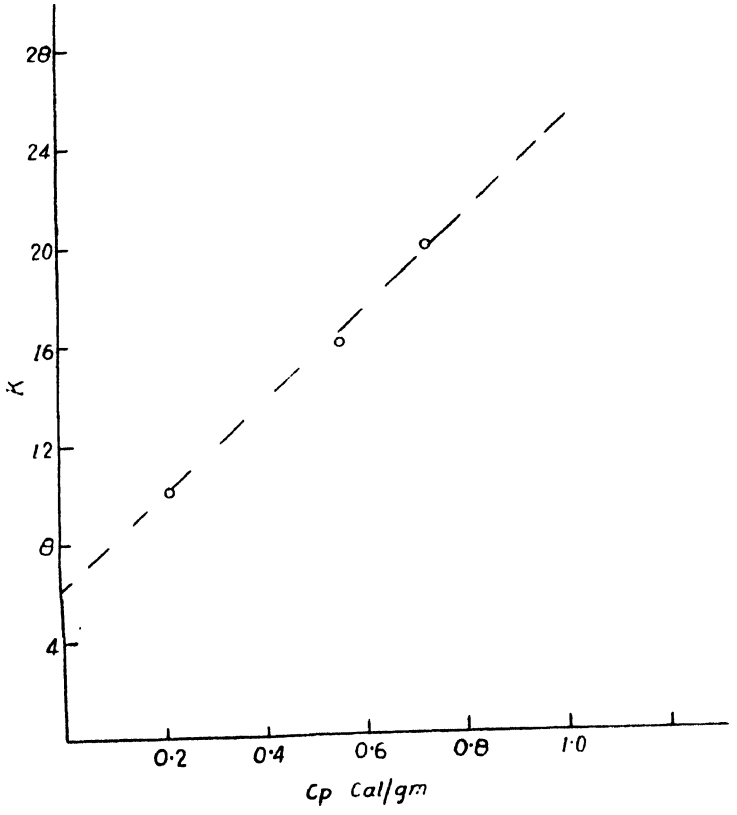

Fig. 4.

Therefore equation (1) becomes

$$\Delta T_{su} = [6{\cdot}0+19{\cdot}0C_p][10]^{3{\cdot}0/R}. \quad \ldots \quad (3)$$

This equation (3) is the relation for predicting the degree of maximum superheat temperature on a rough copper surface. The coefficients 6·0 and 19·0 in eq. (3) may be different for other surface materials and which need to be verified. In a generalized way eq. (3) may be expressed as

$$\Delta T_{su} = [K_1+K_2C_p][10]^{3{\cdot}0/R} \quad \ldots \quad (4)$$

where K_1 and K_2 are constants for a particular material of the surface.

From table 2 and figure (5) it is evident that the maximum superheat values predicted from eq. (3) are in fairly good agreement with the experimentally observed values.

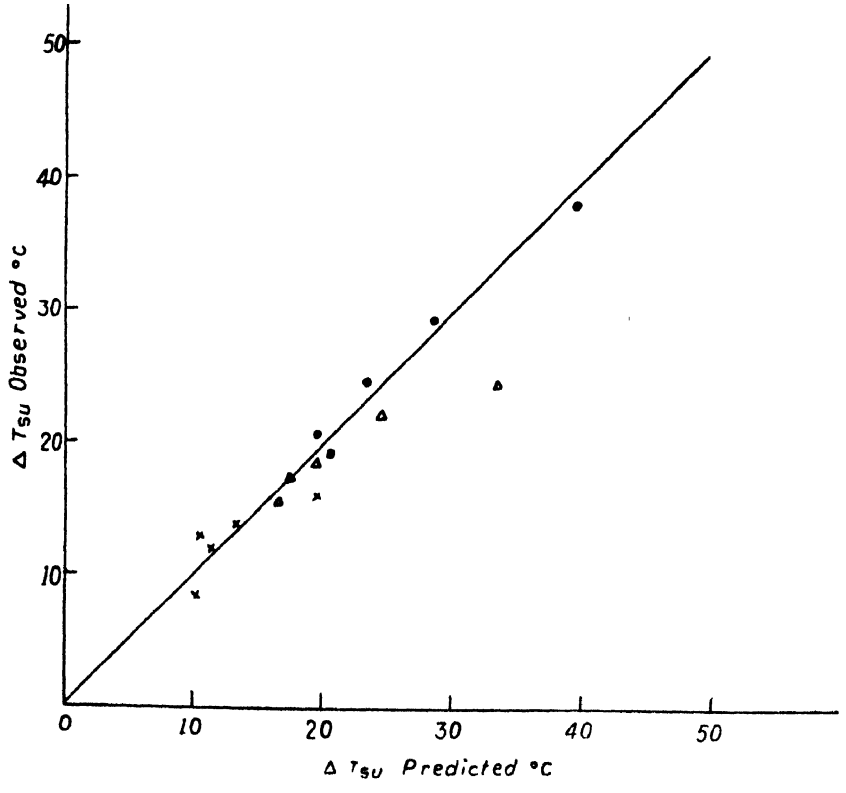

Fig. 5.

Table 2. Comparison of experimental and predicted superheat values

Roughness μ in	Methanol		*n*-Pentane		Freon 11	
	Exptl.	Predicted from eq. (3)	Exptl.	Predicted from eq. (3)	Exptl.	Predicted from eq. (3)
1	—	19580·00	—	16580·00	—	9954·00
5	—	77·94	—	66·00	—	39·63
10	38·0	39·06	24·4	33·08	16·0	19·86
18	29·1	28·74	22·0	24·33	14·0	13·08
30	—	24·65	—	20·86	—	12·53
41	24·6	23·17	18·6	19·61	12·0	11·79
100	—	20·88	-	17·76	-	10·67
165	19·2	20·41	17·2	17·29	13·0	10·38
400	20·8	19·92	15·2	16·87	8·5	10·13

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